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ADVISORY COUNCIL ON SCIENTIFIC RESEARCH
AND TECHNICAL DEVELOPMENT

EXPLOSIVES RESEARCH COMMITTEE (PHYSICS AND PHYSICAL CHEMISTRY)

Studies of shaped charges by flash radiography.

1. Preliminary

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(Radiological Section)

Communicated by the Director M.D.1.

March 15th, 1943.

Summary

It is established that the method of flash radiography can give results of value in such high speed phenomena as the detonation of explosives. Some of the first radiographs obtained during the detonation of various shaped charges are appended.

The duration of the flash is less than 0.5 microsecond and it has proved possible to protect the apparatus from the blast effects of charges up to one ounce in weight while maintaining satisfactory photographic definition and density.

The problem of timing the flash to coincide with the required stage in the detonation has been solved by the use of a detonating fuze device.

Introduction

The photography of shaped charges in their early stages has always been complicated by the intense self luminosity of the explosion. X-rays provide an ideal solution to this difficulty, provided sufficient shortness of exposure can be achieved.

Experiments in the production of intense X-ray flashes had been in progress in the Armament Research Department since early in 1941. Apparatus had been constructed from such components as were available and, whilst awaiting the arrival of an American tube of the field emission type designed by Ehrke and Slack which was ordered in July 1941, a conventional hot cathode X-ray tube was employed. With this apparatus encouraging results were obtained and experiments were contemplated on the functioning of detonators (see O.B.Proc. 18826).

The re-assembly of the apparatus into a transportable unit which could be operated at a site suitable for work on explosives had just been put in hand when the work on shaped charges which forms the subject of this report was suggested. Meanwhile the American tube had arrived and was incorporated in the assembly. It was found to give better control and shorter exposure times than had previously been possible. With the hot cathode tube exposure duration had been of the order of 10 microseconds, but with the new tube exposures of less than 0.5 microsecond were obtained.

The new tube differs from the conventional hot cathode tube in that the source of electrons is a cathode spot initiated by field emission. An auxiliary striking electrode, in close proximity to the cathode, is connected to the anode through a high resistance. On application of the H.T., the intense

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field developed across this narrow gap results in the initiation of field emission from the cathode. The resulting flow of current lowers the potential of the auxiliary electrode on account of the high resistance, and the electron flow is diverted towards the cathode. The cathode shape is arranged to give a focus on the anti-cathode.

After some small scale laboratory trials which included some 1 gramme hollow charges the work was transferred to an outdoor site. Experience in the operation and control of the apparatus in the field had to be gained during the course of the work.

Brief outline of method

Fig. 1 is a simplified diagram of the electrical circuit. Essentially this is a Marx impulse generator, the circuit being operated by the closing of the primary of the small induction coil by means of the thyratron. The resulting spark across the small gap allows the condensers to discharge in series through the X-ray tube.

Operating (or "Triggering") circuit

This operates by the sudden application of a positive potential to the grid of the thyratron which is normally held at a negative potential sufficient to prevent anode current passing. The sudden change of grid potential may be brought about either by breaking or making a suitable circuit.

The triggering impulse was provided by the virtual joining of two adjacent contacts by the ionised gas of the detonation wave front traversing the cordtex. Previous experience has shown that this method is more precise than the usual one of relying on the rise of resistance produced when a wire bridge is ruptured by the passage of the detonation wave. In such cases, the rise in resistance is liable to be delayed till the concentration of the ionised gas has fallen to some indefinite extent.

Control of moment of operation

The duration of the discharge, that is to say, the exposure time, is fixed by inherent tube characteristics. With the tube and apparatus employed it was appreciably under 1 microsecond and probably of the order of $\frac{1}{4}$ microsecond.

There is always a delay between the moment of triggering and the production of the X-ray flash. It is dependent upon the characteristics of the thyratron, the length of the thyratron grid leads, the induction coil and other parts of the circuit. It does not remain absolutely constant under the same circuit conditions but fluctuates about a mean value. It has not yet been found possible to reduce this mean value below about 30 microseconds with a fluctuation of ± microseconds. To obtain radiographs at very short intervals after firing it is, therefore, necessary to allow for this delay by triggering the tube before the actual detonation of the charge is started.

This advance triggering was achieved as indicated in Fig. 2. A length of cordtex detonating fuze was used to initiate the detonation of the charge and the triggering contacts were placed at a suitable position along the length of the cordtex. From the known velocity of the detonation wave along the cordtex (approximately 7 millimetres per microsecond) any desired triggering could be given.

The sequence of events becomes

(1) The initiation of the detonation wave in the cordtex by an electric detonator A.

(2) Triggering impulse when the detonation wave reaches B.

(3) Initiation of detonation in the main charge when the detonation wave reaches C.

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At first sight it might appear that the delay between the triggering and the X-ray flash could be more simply eliminated by the use of a suitable timing circuit and an electric detonator, rather than the device shown in fig.2. The time functioning of such detonators is susceptible to variations which are quite large in the time scale of detonation phenomena. Their use in an accurate timing circuit is, therefore, prohibited. Experience has shown that the detonation wave along cordtex is extremely constant and the arrangement of fig.2 is reliable.

In practice, on account of the variable delay in the functioning of the X-ray tubes, precise timing is not actually obtainable and several attempts may be necessary to obtain a particular stage of the action but a series of radiographs covering a range of times can be obtained without undue difficulty.

Protection of apparatus and film

To obtain good definition in a radiograph it is, of course, desirable to place the object being radiographed as near as possible to the film but in dealing with even very small exploding charges it is obviously necessary that there should be some appreciable space between them. The loss of definition resulting from this separation of film and object can be overcome by placing the X-ray tube further away, so increasing the over all tube-film distance. Since the radiation intensity varies as $1/D^2$ and the photographic effect, owing to the characteristics of the intensifying screens and the film varies still more rapidly (approximately as $1/D^{2.7}$) the extent to which distance can be increased and still retain adequate film density is limited.

For protection of the apparatus and film steel plate could not be used with the apparatus employed because of its high X-ray opacity. The condensers available only allowed a maximum tube voltage of 180 K.V. and at this voltage useful exposures can only be obtained through $\frac{1}{4}$ to $\frac{3}{8}$ inch of steel or its equivalent. Aluminium plate placed at a sufficient distance from the charge had therefore to be used.

It was found possible to increase the tube-film distance from the 36 inches originally used to 48 inches and still obtain adequately exposed films. As the tube could, therefore, be at a distance of two or three feet from the charge its protection was not as difficult as was anticipated. Use was made of a convenient air-raid shelter. The tube was set up just inside the shelter entrance, the high tension leads being taken through insulating bushes fixed in the back of the shelter and connected to the apparatus housed in a lorry behind. The shelter entrance was closed by a welded steel screen which is shown in the photograph Fig.4. A small window was cut in the screen opposite the tube target and was covered originally by a $\frac{3}{8}$ inch plate of aluminium but later by 5/16ths inch of paxolin because of its lower X-ray absorption.

The protection of the photograph film presented more difficulty. The final arrangement appears in Fig.2. The main protection consists of an aluminium plate $\frac{1}{2}$ inch thick. A one ounce charge at 2 inches distance from this plate produced a dent of height about $\frac{3}{8}$ inch, when the edges of the plate were rigidly supported. The film and intensifying screens were therefore spaced away from the rear of the plate by an air gap of $\frac{1}{2}$ inch. The film was also protected from blast by enclosure in a strong welded steel box, of which the main aluminium plate formed the lid. In order to avoid frequent renewal of the $\frac{1}{2}$ inch plate on account of surface damage a thinner ($\frac{1}{8}$ inch) plate was placed in front which could be renewed as necessary. A sheet of paper had to be interposed between these two plates otherwise they became welded together. The cassette was not restrained in any way. It can be shown that its maximum possible displacement even when exposure was delayed more than 40 microseconds after firing, was quite negligible.

Results

The radiographs attached to this report show :

Sheet (1) The detonation of cordtex.
(a) with separate copper wire indices at 2 cm. intervals.

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(b) between continuous strips of lead foil, 0.003 inch thick, attached to the sides of the cordtex.

Sheet (2) The detonation of separate Munroe charges at different intervals of time after detonation.
The details of these Munroe charges are:-

Diameter of charge	6mm.
Weight of charge	0.56 grammes P.E.
Lining shape	80° cone
Lining thickness	0.12 mm.
Lining material	Copper
Case thickness	0.12 mm.

If the delay in the X-ray apparatus be taken as constant, the displacement of jet and plug can be plotted against time as in Fig.3. The variations in tube delay make the velocities so obtained subject to considerable error. The plug velocity is about one-tenth of the velocity of the head of the jet. The estimated jet velocity is in the region of 20,000 fs, which may be compared with the results obtained for these charges by spark photographic methods of 15,000fs (Phys/Ex.393).

It is hoped that the uncertainty in the radiographic timings will be reduced in later work by the use of an additional branch of cordtex which will appear on the radiograph. The progress of the detonation wave down this branch will provide a clock giving an independent time measurement.

So far as can be judged from these radiographs the Munroe cone appears to collapse into a spindle. An interesting feature, which from the radiographs seems quite reproducible, is the periodic structure of the later portions of the jet.

Conclusions

It will be evident from the preliminary results obtained that the flash radiographic technique will be invaluable in many branches of explosive work.

It is hoped that during further experimental work it will be possible to study the detonation of

(1) 30 mm. diameter Munroe charges.
(2) Cylindrical bombs filled P.E. and Torpex.
(3) Plain explosive cartridges in which density variations in the detonation wavefront may be visible.

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FIG. 1.

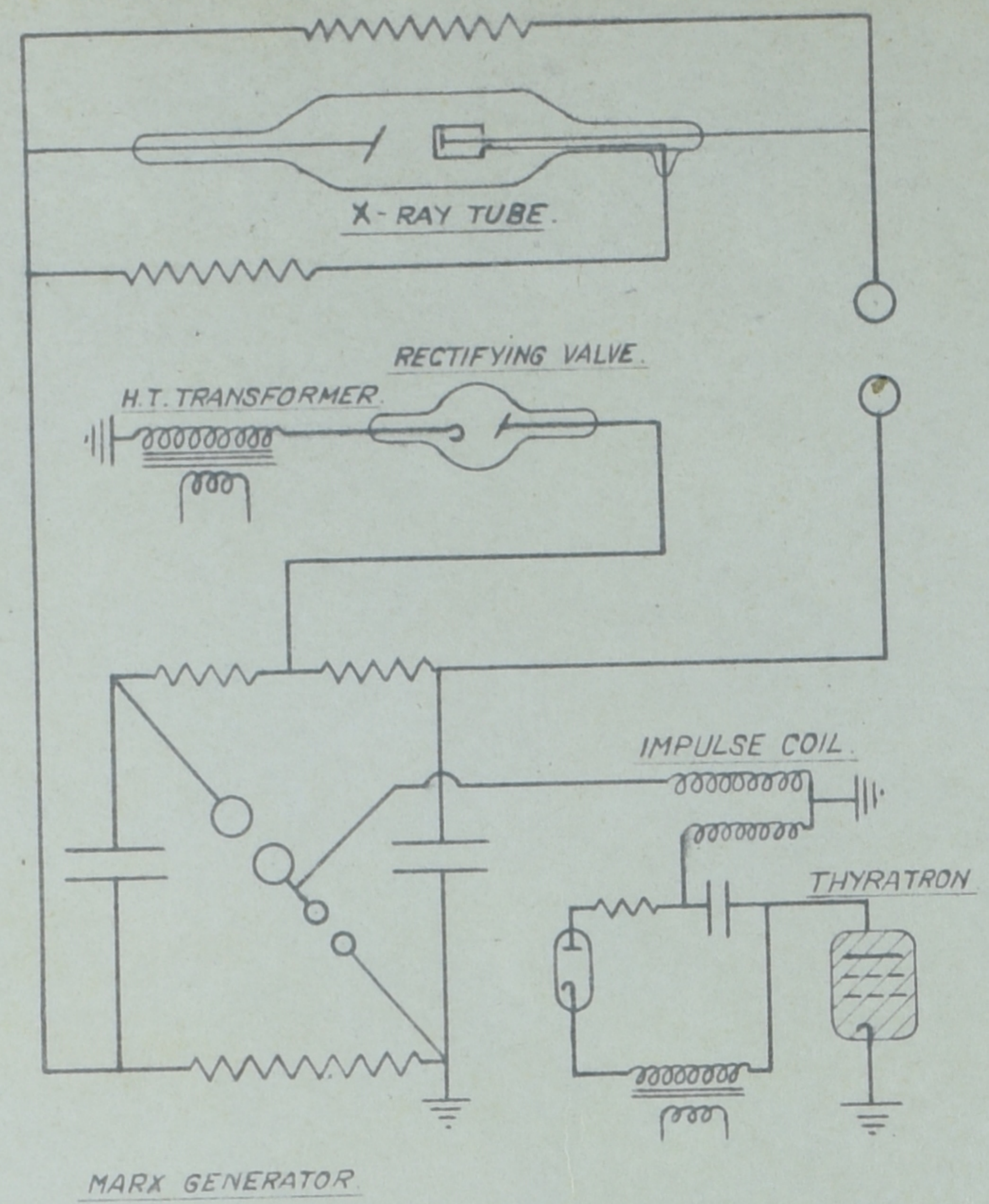


FIG. 2.

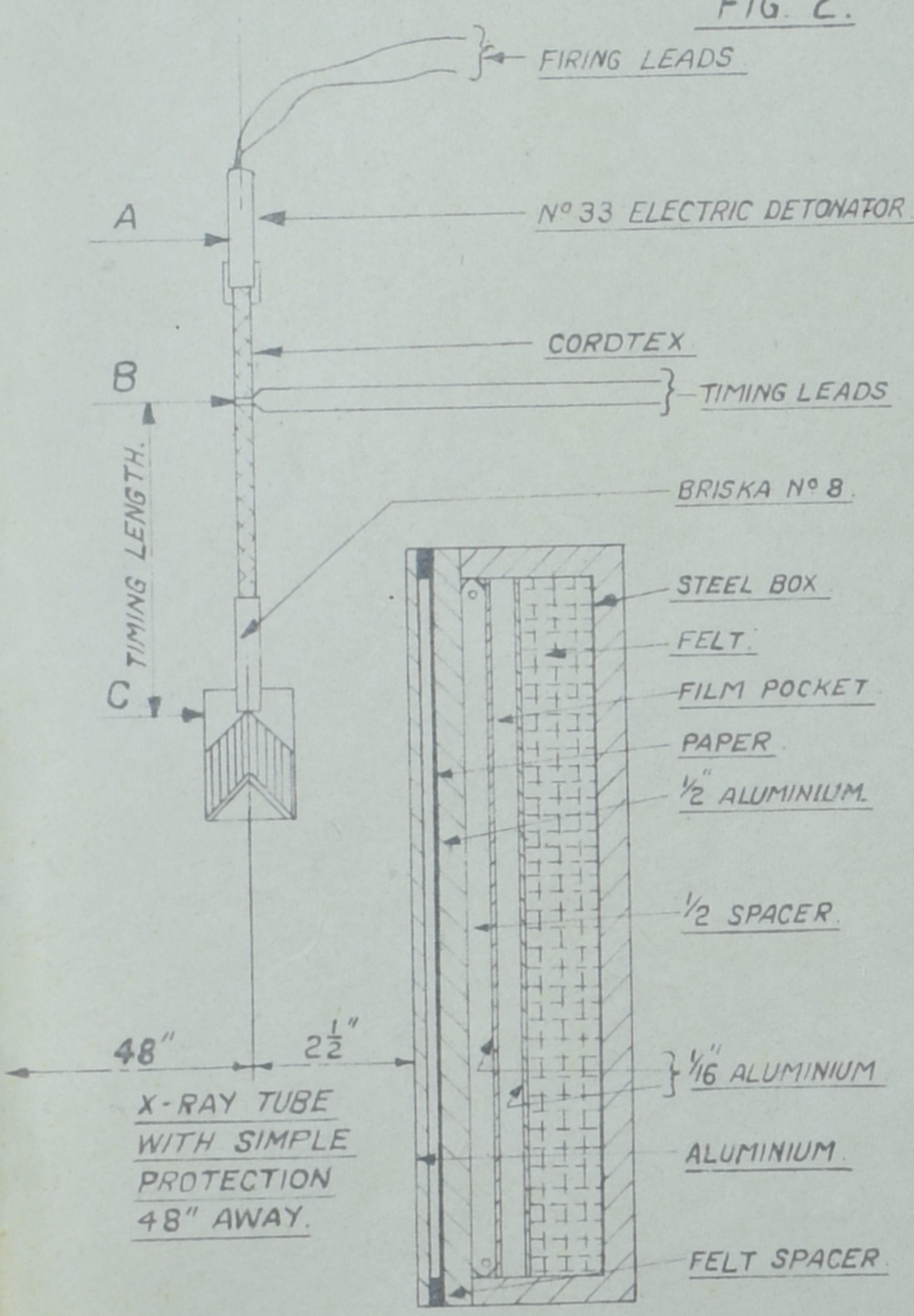
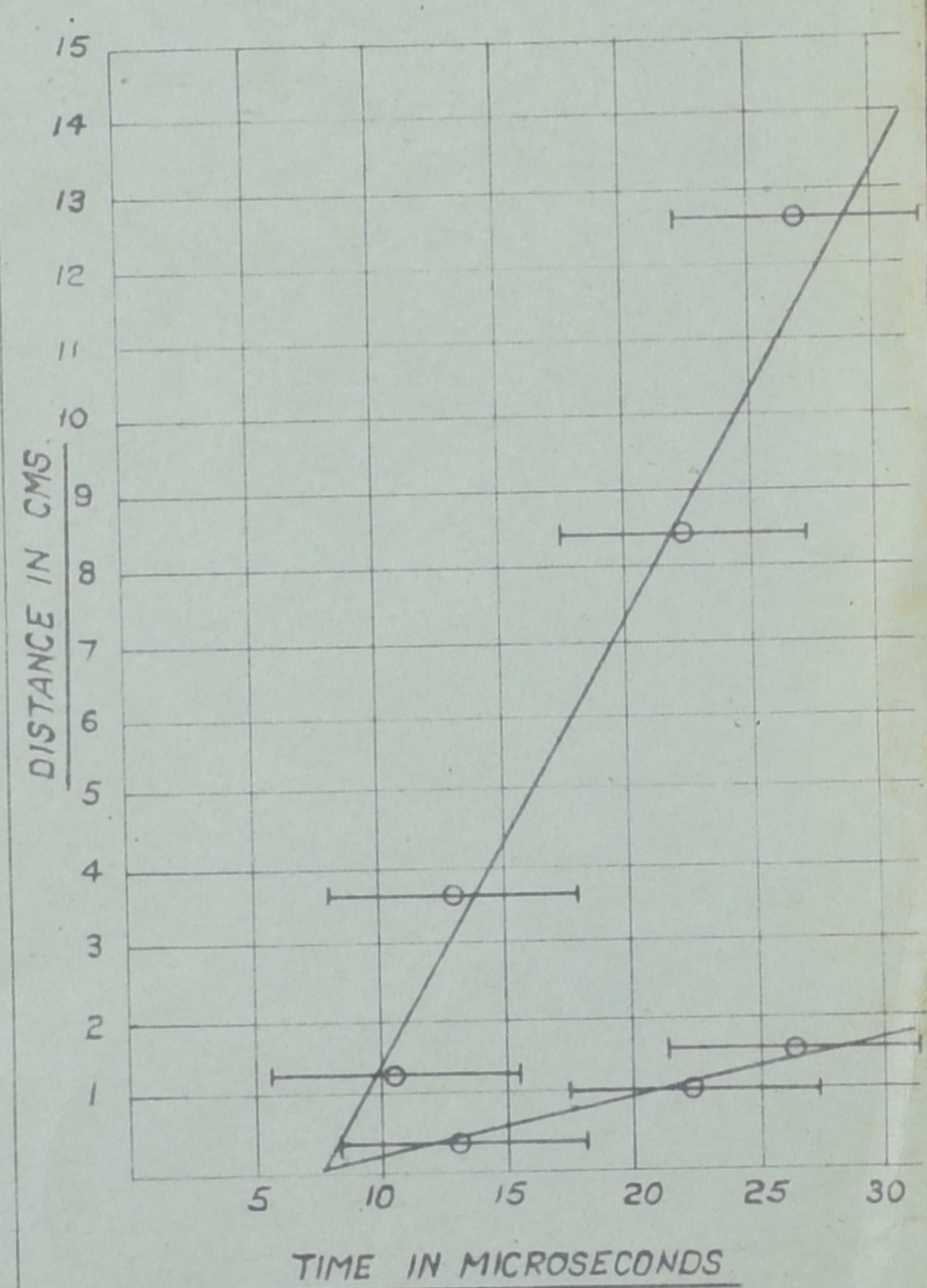


FIG. 3



FLASH RADIOGRAPHY OF SHAPED CHARGES.

A.R.D. SKETCH Nº F 12733.

Fig. 4.

Photograph showing steel screen for protection of X-ray tube and charge and cassette in position.

Flash radiographs of the detonation of Cordtex.

(Velocity of detonation wave about 7 mm. per microsecond)

During detonation.

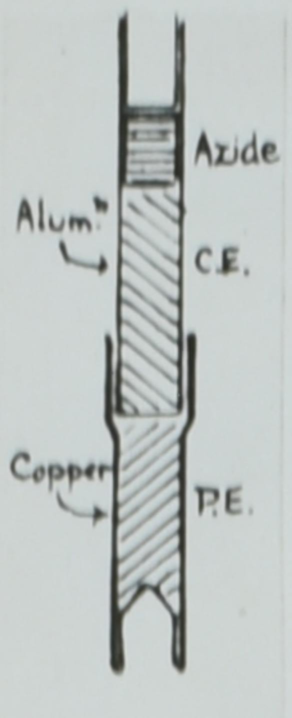
Copper wires twisted round Cordtex at 3 cm. intervals.

Before detonation.

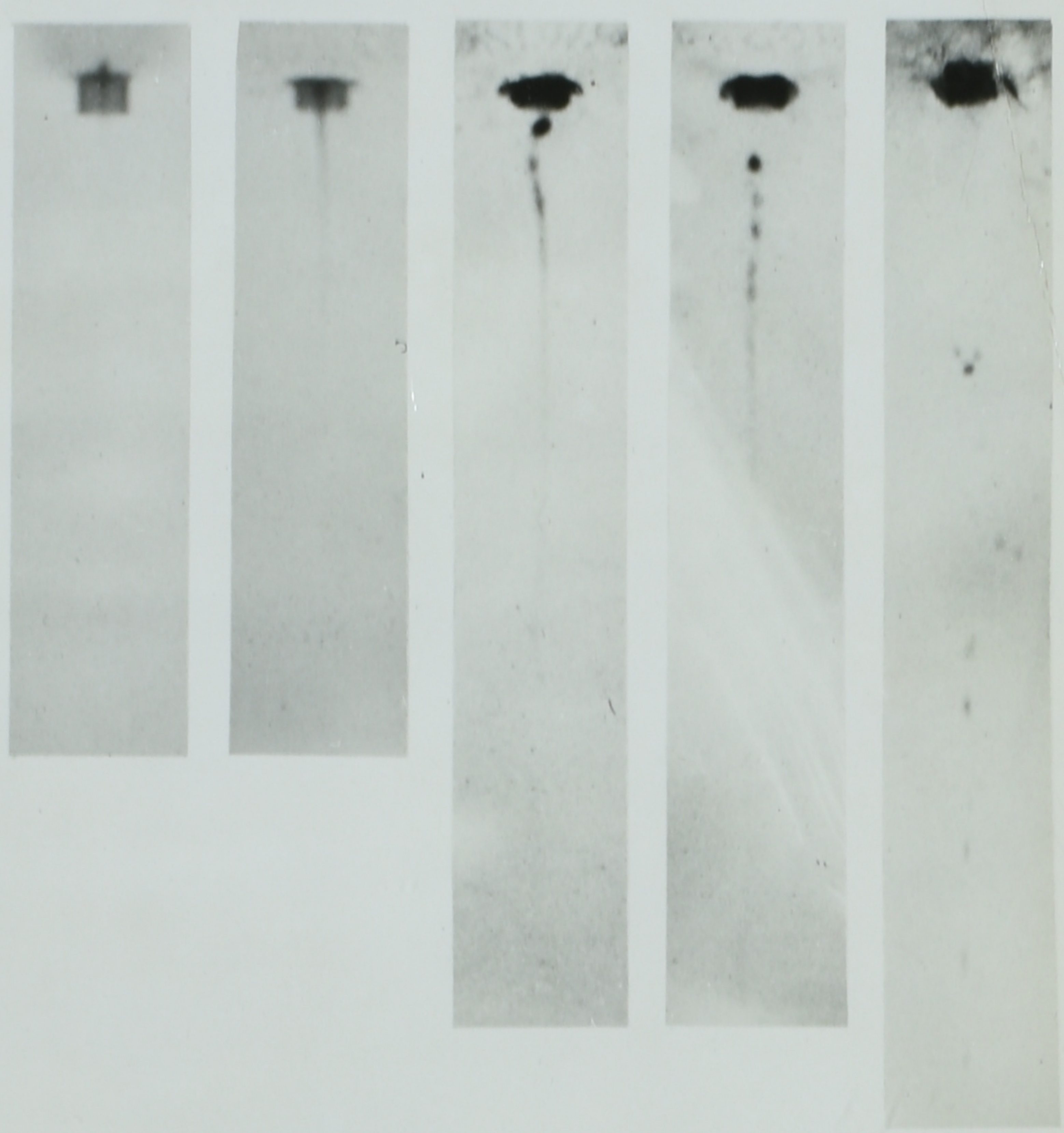
During detonation.

Lead foil strips on either side of Cordtex.

Flash radiographs of small hollow charges.



Diameter of charge	6 m.m.
Weight of charge	0.56 grammes P.E.
Lining shape	80^o cone.
Lining thickness	0.12 m.m.
Lining material	Copper.



Time after initiation of detonator	-	11 microsecs.	13 microsecs	23 microsecs.	28 microsecs.	50 microsecs.
	Detonator just firing azide beginning to expand.	Jet just forming.	Jet formed	Plug just clear of casing.	Jet beginning to break up.	Jet broken up into discrete particles.